Generator Protection

Generator Protection

Purpose

- Generator, prime mover
- External power system, processes it supplies

Considerations

- Expense
- Risk
- Continuity of service
- Damage to system, processes it supplies
- MW rating
- Utility interface requirements

Basler

ANSI/IEEE Device Numbers

- Protective relays are generally referred to by standard device numbers
- Letters can be added to clarify application

Examples :

- 51 is a time overcurrent relay
- 50 is an instantaneous overcurrent
- 27/59 is a combination under/over voltage relay
- 87T is a transformer differential relay
- 59G is a ground overvoltage relay

Basler

Device numbers commonly used

Protective Function	ANSI code
Stator Differential	87G
Underimpedance	21
Current Unbalance	46
Loss of Excitation	40
Reverse Power	32
Thermal Protection	49
Breaker Failure	50BF
Time Overcurrent with Voltage Restraint	51V
Stator Ground	64G
Ground Fault Overvoltage	59N
Ground Overcurrent	51GN
Over-excitation	24
Phase Sequence Voltage	47
Overvoltage	59
Undervoltage	27
Over and Underfrequency	81

Basler

Types of Protection

Faults

- Ground fault
- Phase fault

Abnormal operating conditions

- Reverse power
- Loss of field
- Thermal
- Uncleared external fault
- Overexcitation
- Negative-sequence overcurrent
- Off-frequency operation

Ground Fault Protection

Level of fault current

- grounding impedance (low, medium, high)
- location of fault in winding
- pre-fault voltage level

Fault near generator neutral

- low probability due to less insulation stress (mostly mechanical)
- Protection goal: ≤ 10% of winding uncovered

Selectivity

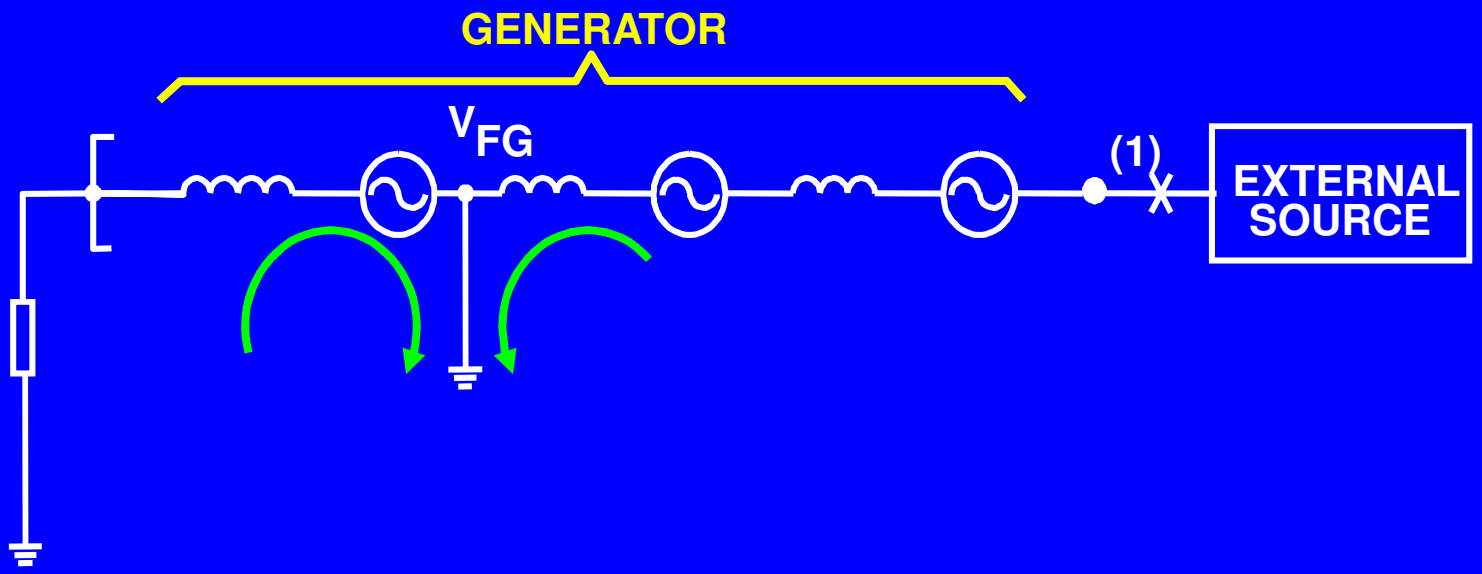
- determined by system configuration and relay scheme

Grounding impedance

Grounding impedance	High	Medium	Low
Ground fault current limited to	3% In	5% to 40% In	>In
Description	- Limit damage during a fault	- easy detection of ground fault location	- when it is important that the power source is effectively grounded
	Ground fault elevated the sound phase voltages to a nominal 173% of rated.	- limit arcing fault overvoltage	- limit overvoltage during fault on line-ground connected load
		- only a moderate damage limitation needed	

Basler

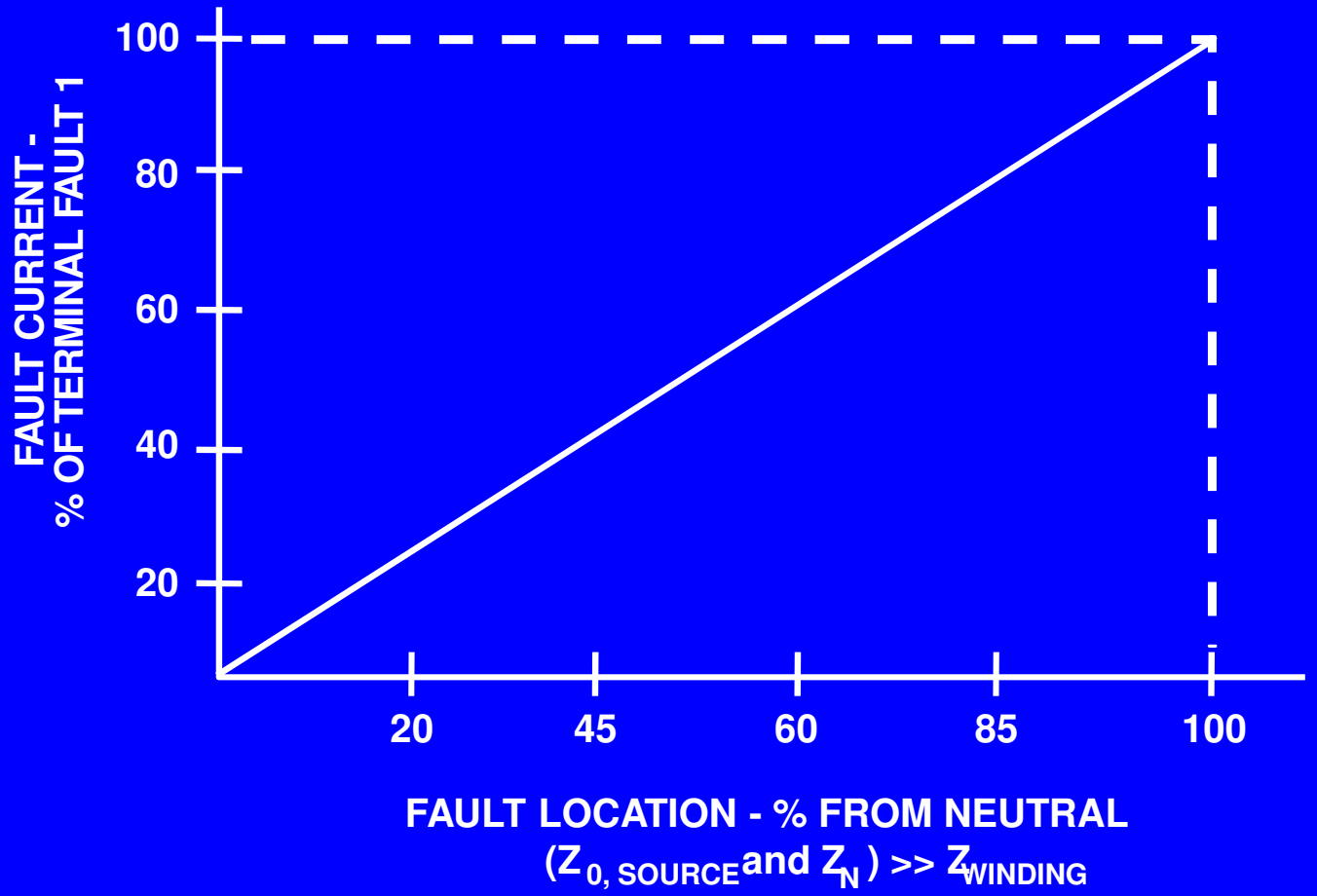
Summary: Level of Ground Fault



Fault current level depends on:

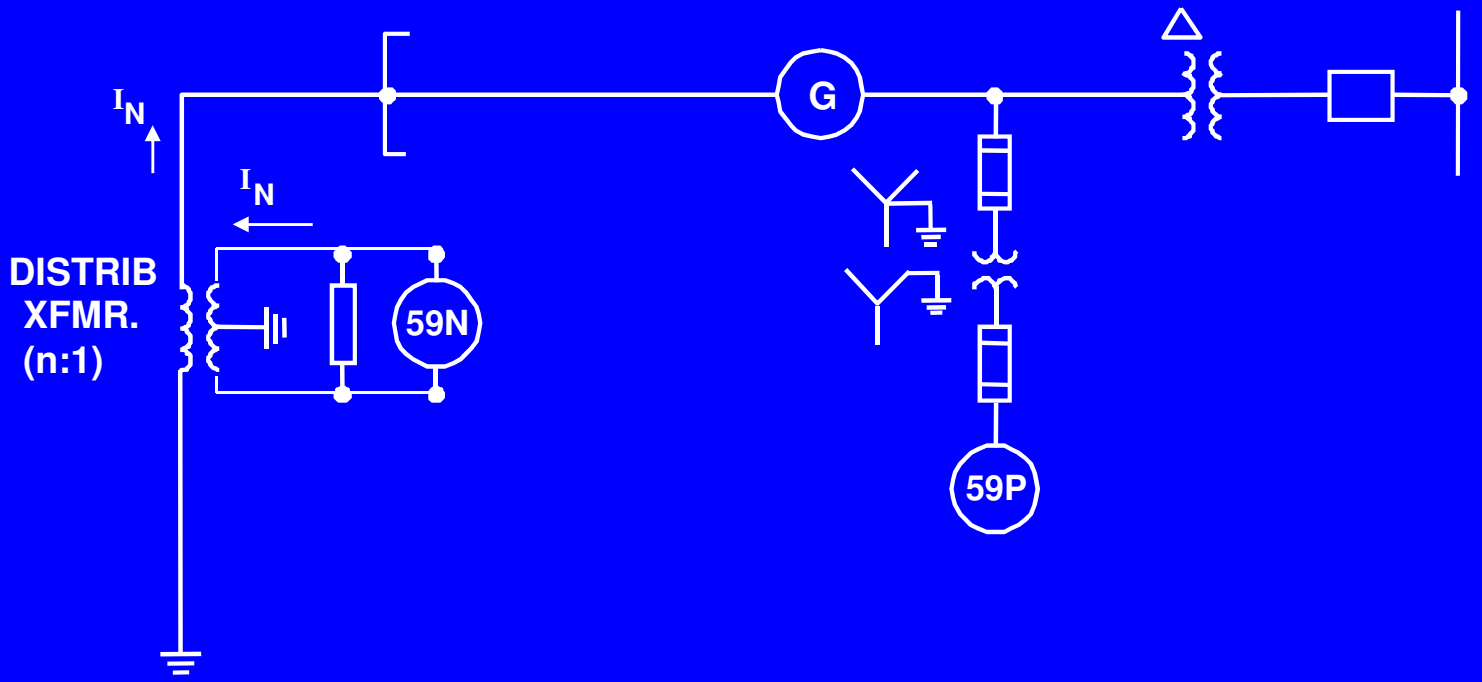
- **location of fault relative to generator neutral**
- **voltage at fault point**
- **generator grounding impedance (low, med, high)**

Generator ground fault current level - High impedance grounded system



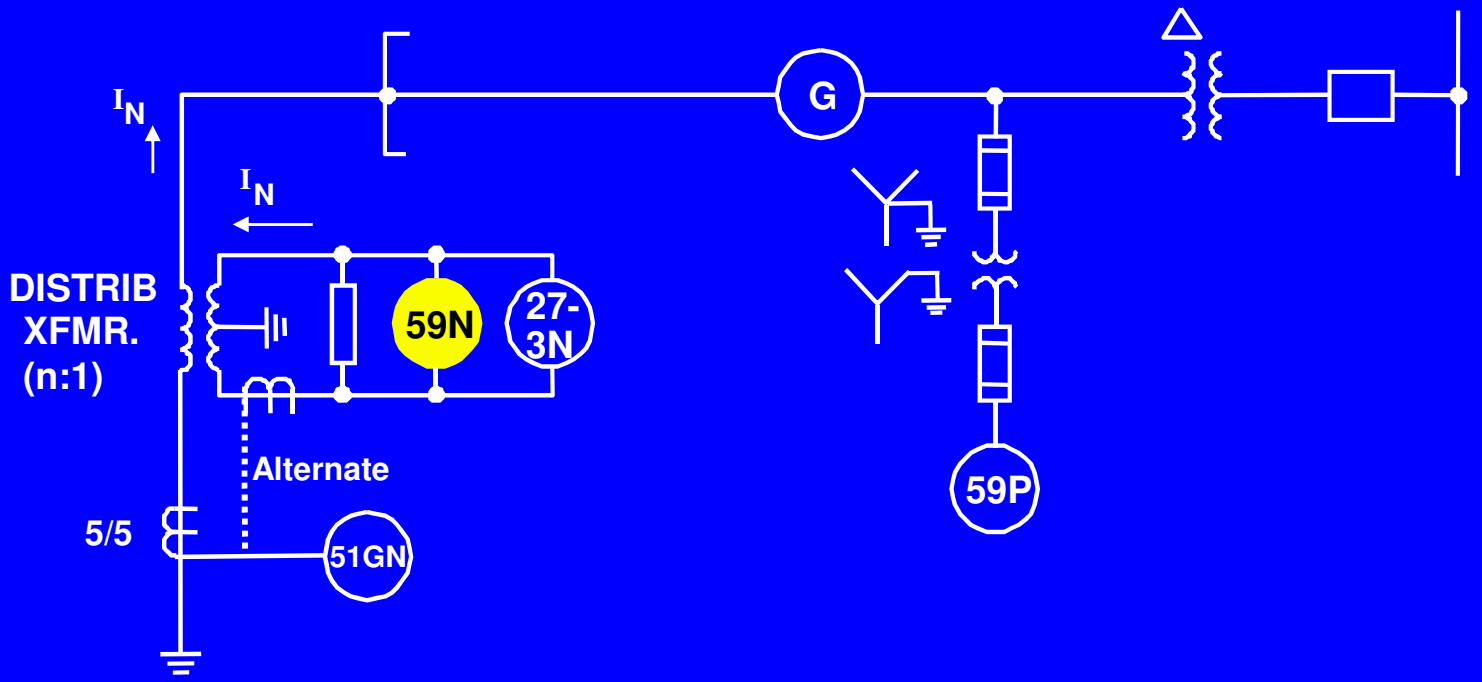
- Fault voltage level is proportional to the location of fault from the generator neutral
- High to moderate neutral or fault impedance will make fault level proportionate to voltage

Phase-ground Fault: High resistance grounding



- Resistor size
  - terminal fault current of 5-10 A primary
  - based on generator line-ground capacitive reactance
- Low fault current minimizes generator damage
- I_N contains 3rd harmonic

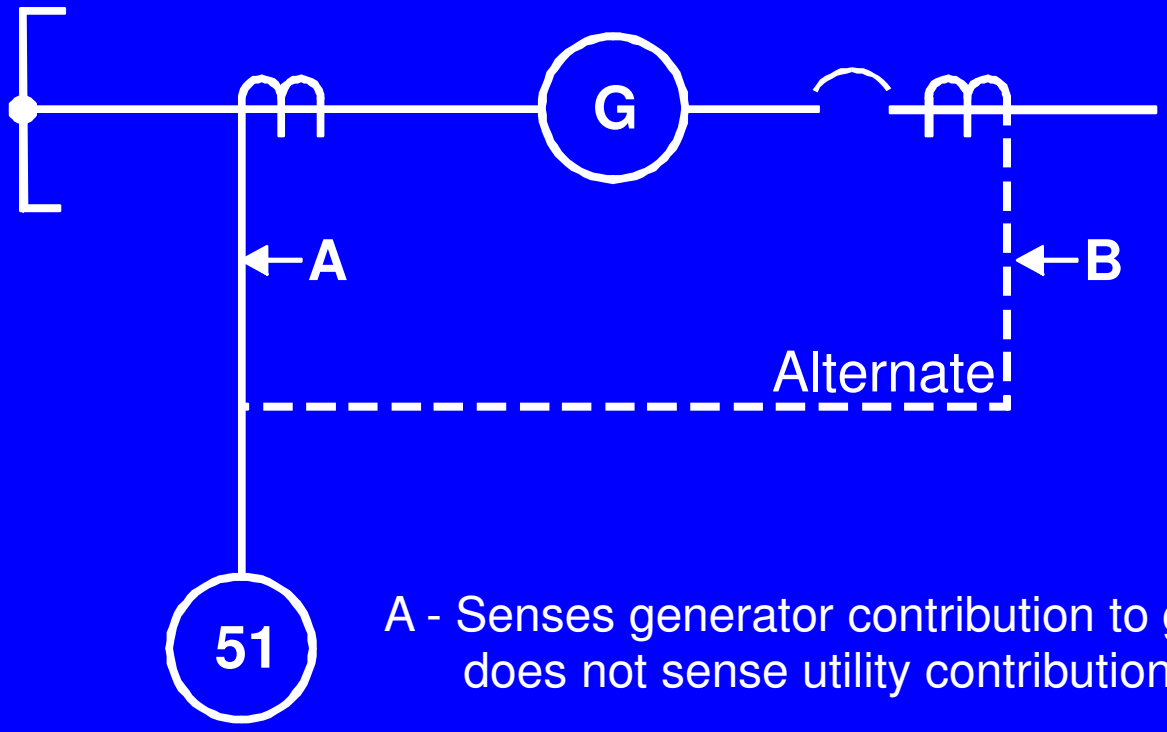
Phase-ground Fault: High resistance grounding



Low fault current

- 87G will not operate
- 59N provides ground fault protection for most of stator ground faults
- Like overcurrent relays, 59N is blind for faults near neutral

Phase fault



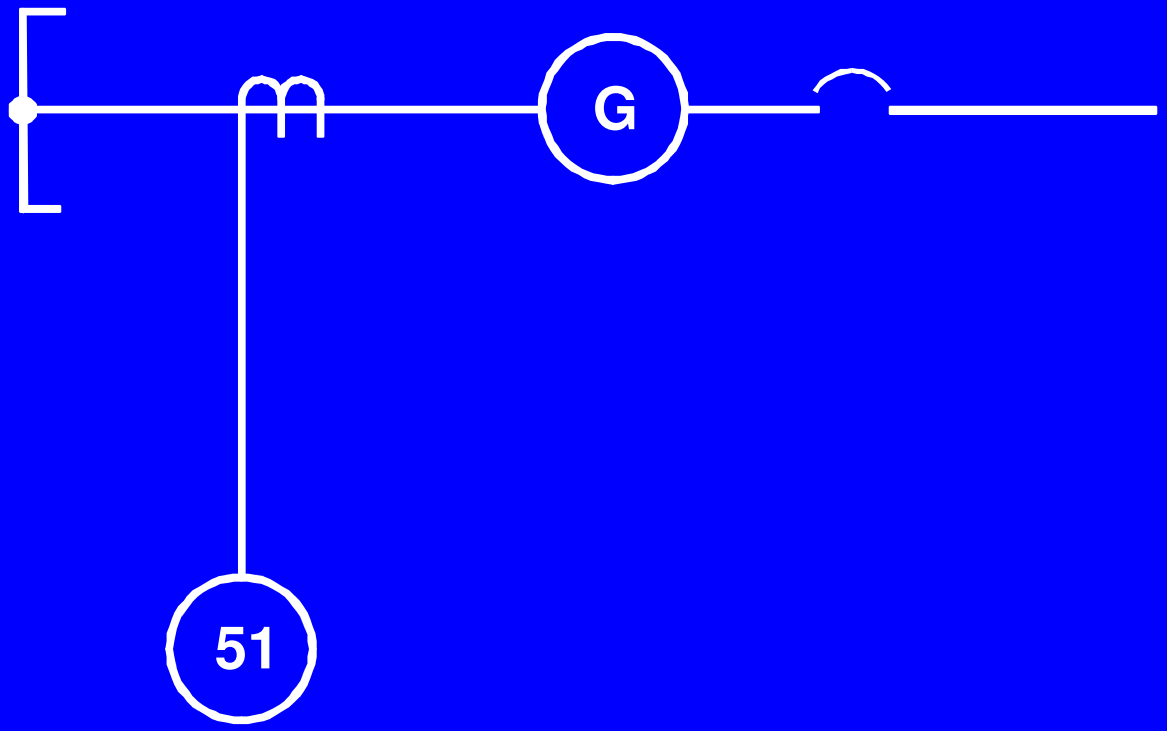
A - Senses generator contribution to generator fault; does not sense utility contribution to generator fault.

B - Senses utility contribution to generator fault; blind to generator fault when breaker open and when running isolated from utility.

- **51 is simplest phase fault protection**
- **Fault clearing delayed as 51 coordinates with down-stream relays**

Basler

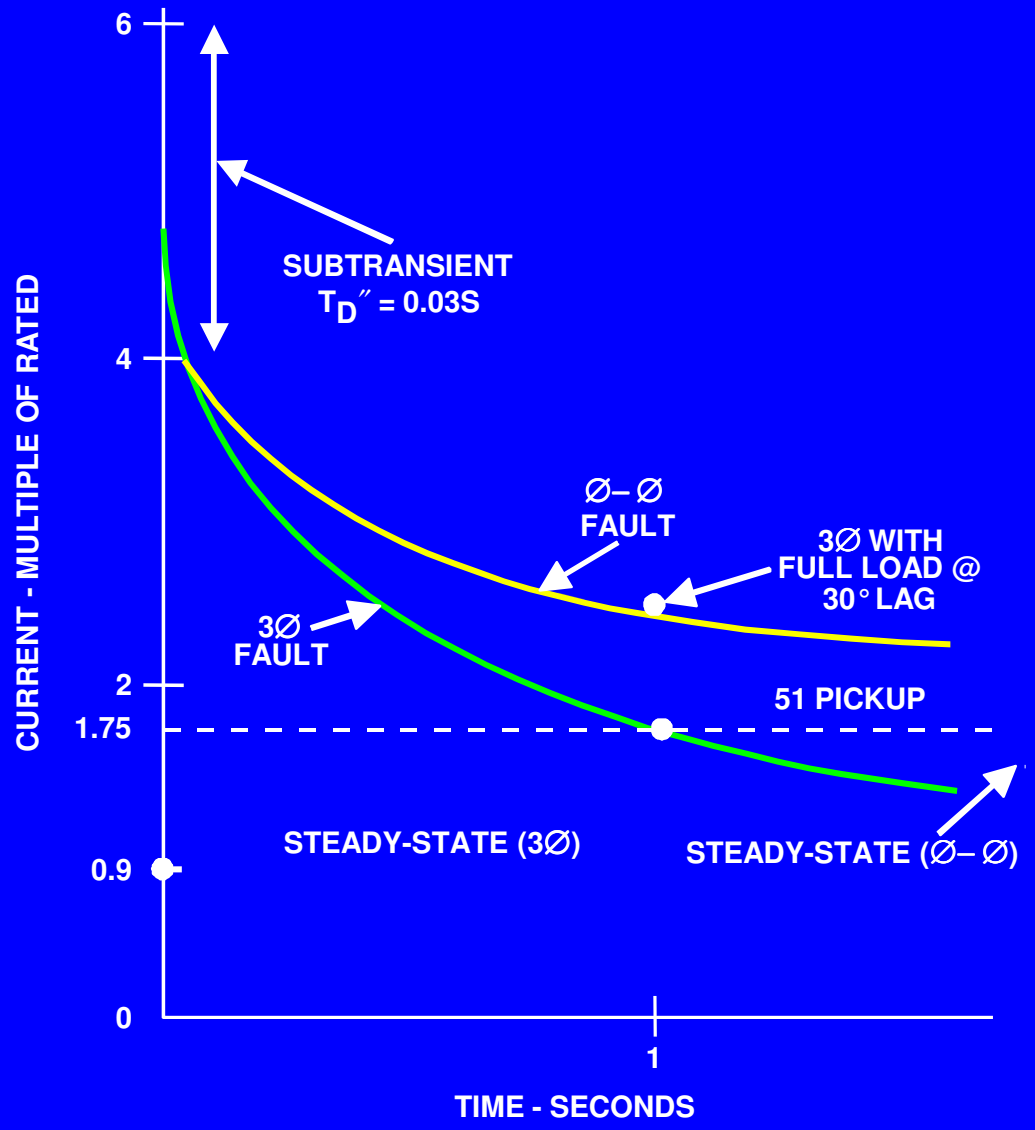
Phase-phase fault



Typical setting should be 175% of rated current

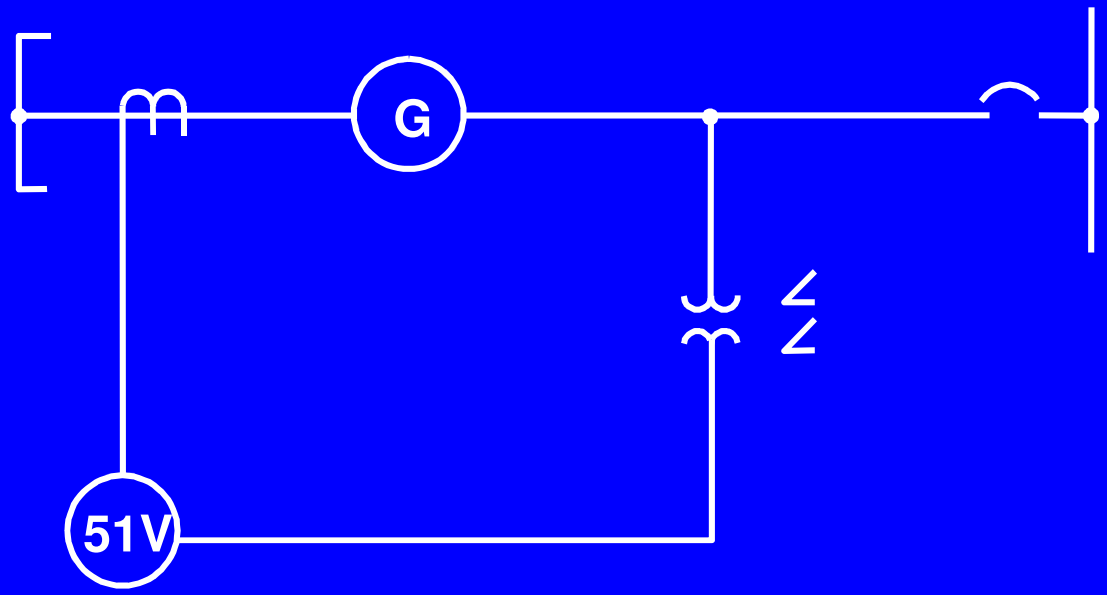
- override swings due to slow clearing external fault
- starting of motors
- transformer energization

Phase fault: Generator fault current decay



- 51 must operate before current decays below MPU
- 3Ø fault is worst case
- Pre-fault load current provides more time to operate

Voltage-restrained TOC Relay 51V

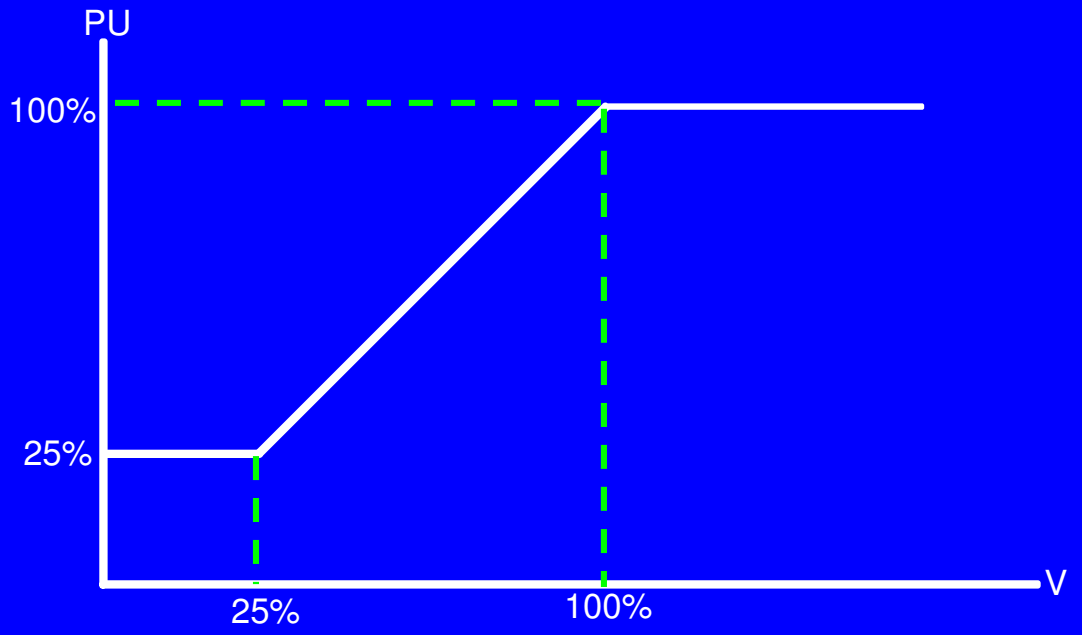


- Pickup of relay depends on voltage
- Relay must not pickup at full load and normal voltage

Voltage-restrained TOC Relay 51/27VR

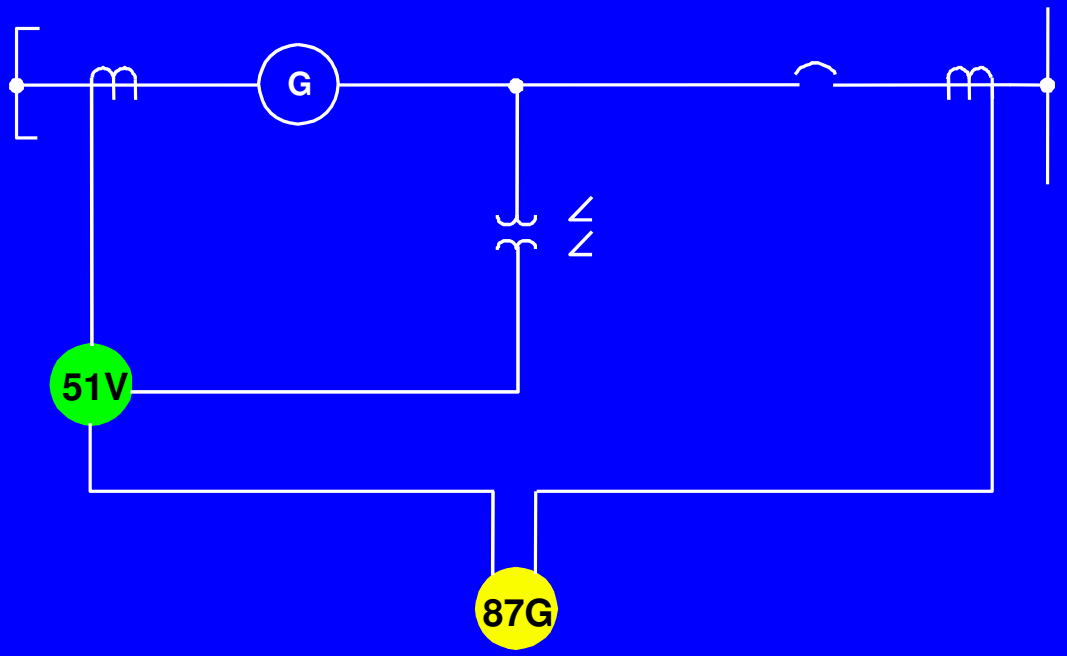
- 51V relay pickup decreases with decreases in the voltage
- Voltage restrained: 51/27R
  - MPU set above rated current (typically 175%)
  - MPU proportional to voltage: decreases when fault occurs
  - More work to coordinate
  - More secure from swings and motor starting
- 51V less susceptible to operation on swings of motor starting condition that depresses the voltage

Voltage-restrained TOC Relay 51/27VR



- If relay pickup is set at 175% of rated current:
  - relay picks up at 175% of rated current at 100% rated voltage
  - relay picks up at 44% (25% of 175%) of rated current at 25% voltage

Phase fault differential protection 87G



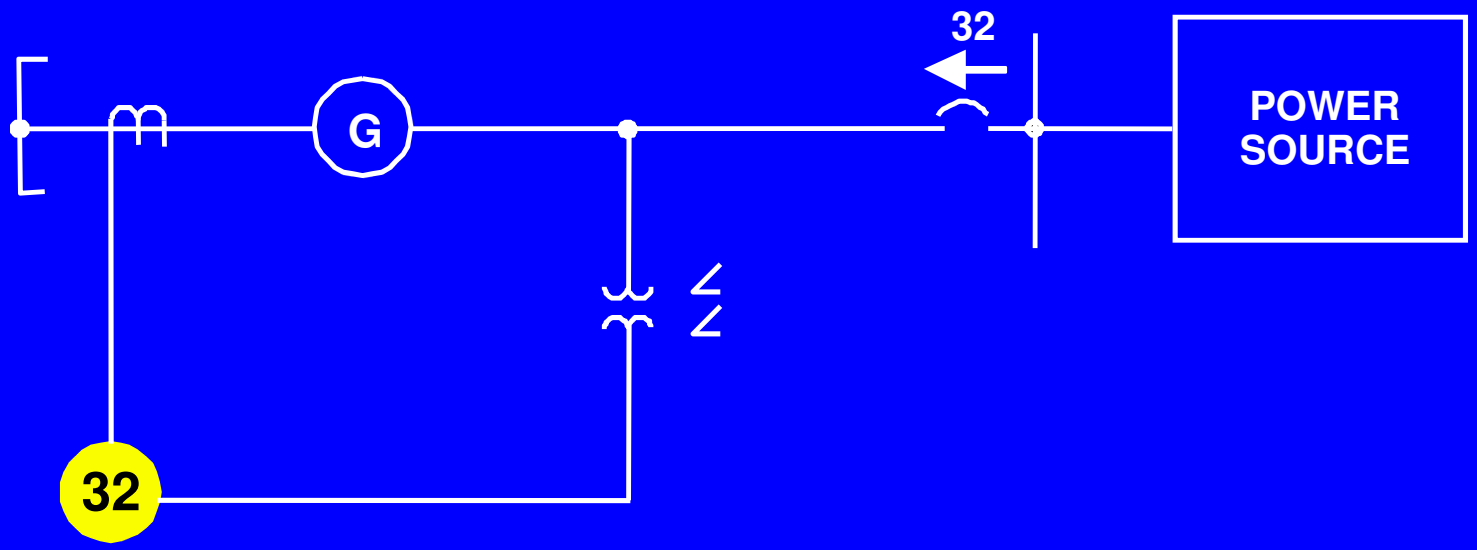
- 87G provides fast phase fault protection
- 87G immune to load current and external fault
- CTs on both sides must be of same ratio
- Sensitivity (setting) depends on CT quality
- 51V backs up 87G and external relays

Reverse Power Protection

- Power flows to generator due to failure of prime mover input
- Prime mover failure can
  - cause overheating of low pressure blades in steam turbine
  - create fire hazards due to unburnt fuel in diesel generator set
  - cause mechanical damage to gas turbine

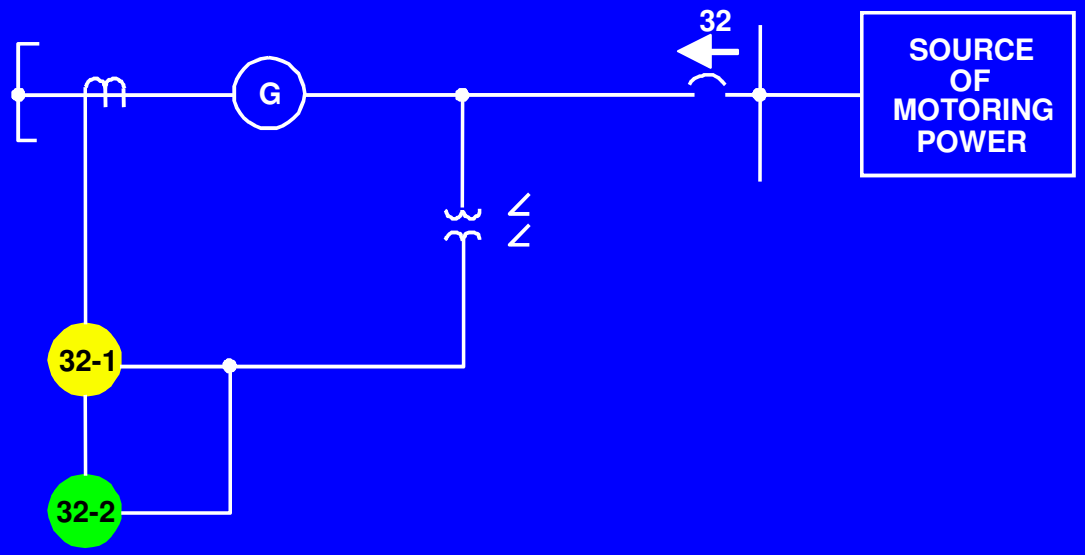
Basler

Reverse power protection



- 32 senses real power flow into the generator.
- Typical time delay setting for 32 should be 15 seconds (synchronizing).
- CT location is not important for 32 operation.

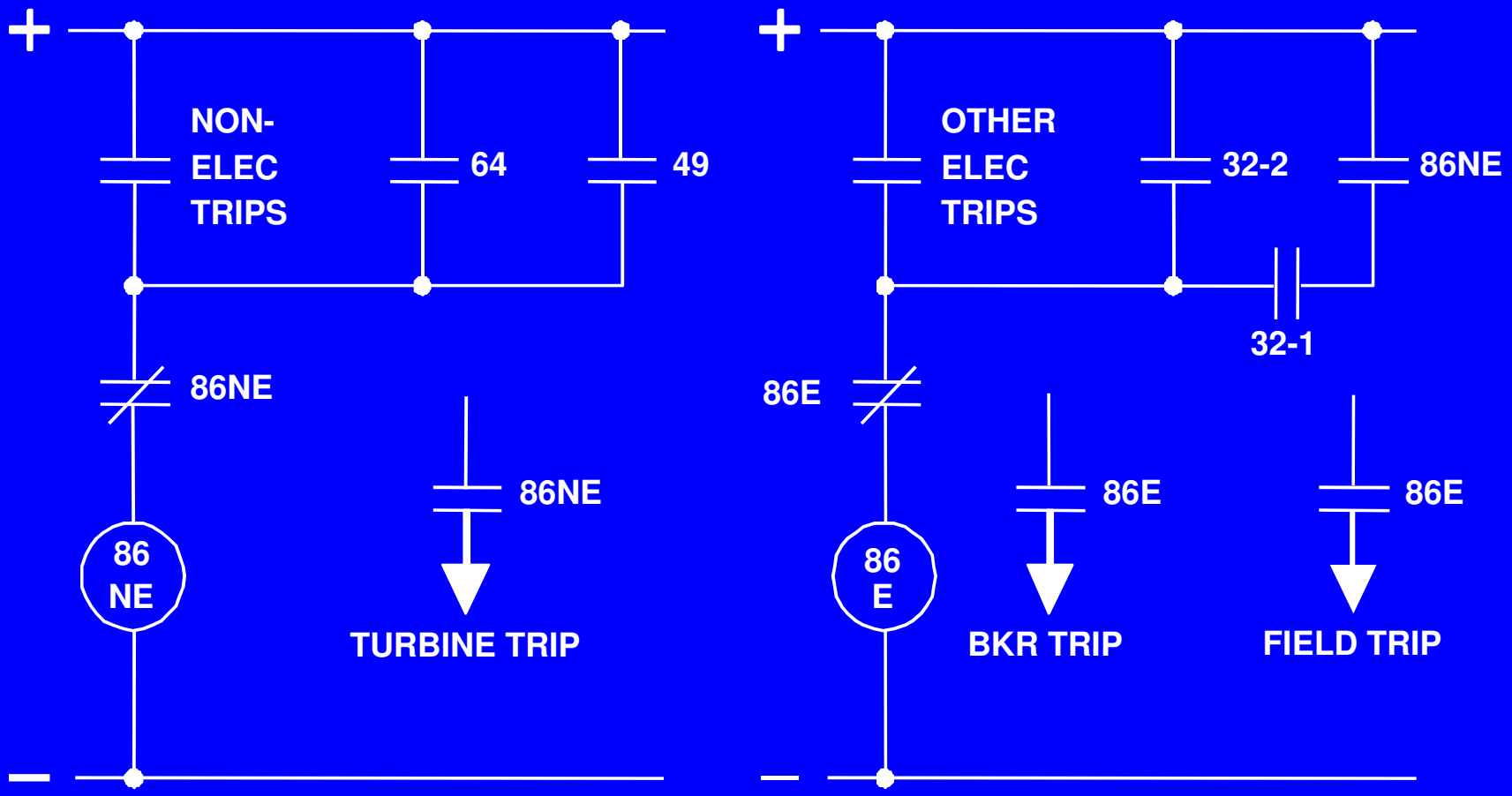
Reverse power protection



- 32-1 relay supervises generator tripping relays until motoring occurs (delay @ 3s)
- 32-2 trips generators directly, e.g. for governor control malfunction (delay @ 15-30s)

Basler

Reverse power protection



Basler

Reverse power protection

Prime Mover	Motoring Power (% of rated)	Protection Setting
Diesel Engine	5-25	50% of motoring power
Gas Turbine	10-15 (split shaft) >50% (single shaft)	
Hydro	0.2-2 (blades out of water) >2 cavitation (blades in water)	
Steam Turbine	0.5-6	

Basler

Loss-of-field protection

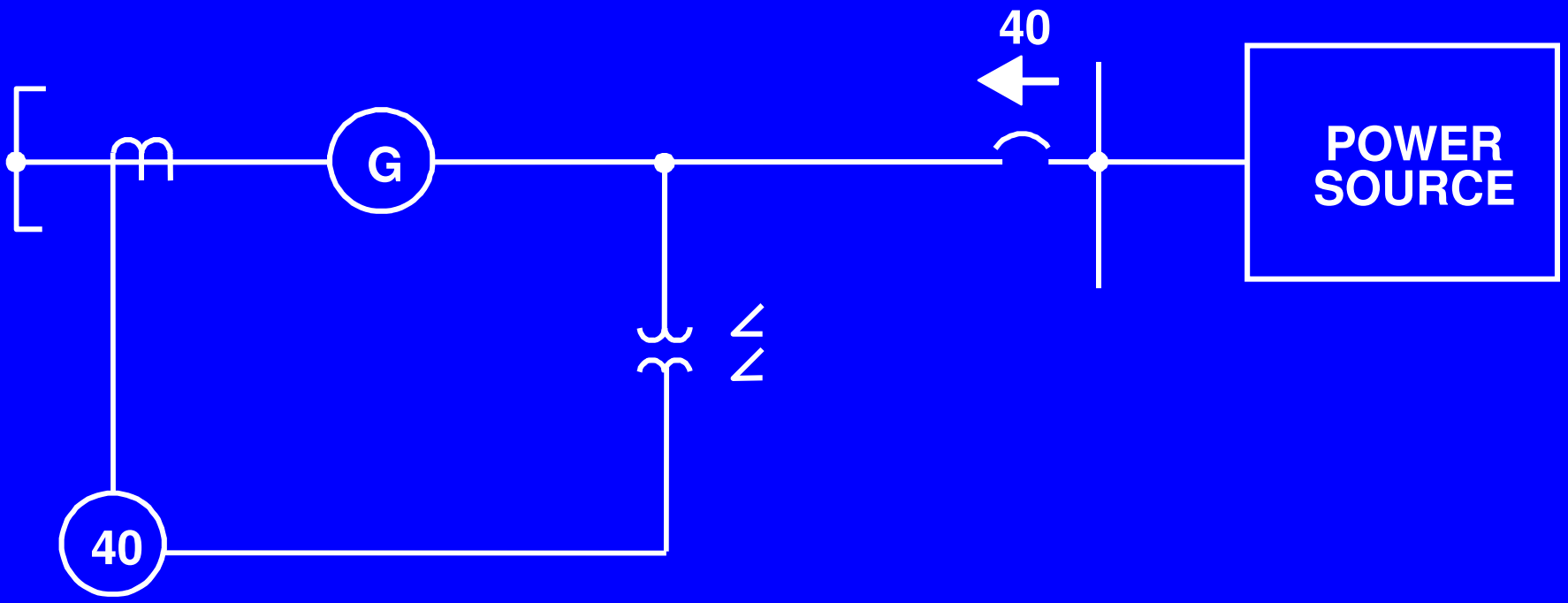
- Generator eventually runs as induction generator with complete loss of excitation.
- Machine runs above synchronous speed, i.e. negative slip.
  - Excessive current can flow in rotor winding and cause overheating.
  - Stator thermal overload relay 49 cannot detect this condition.
- Rotor thermal overload can occur even due to partial reduction of field
  - due to operator error or regulator malfunction
- Minimum Excitation Limiter is backup to relay

Loss-of-field protection

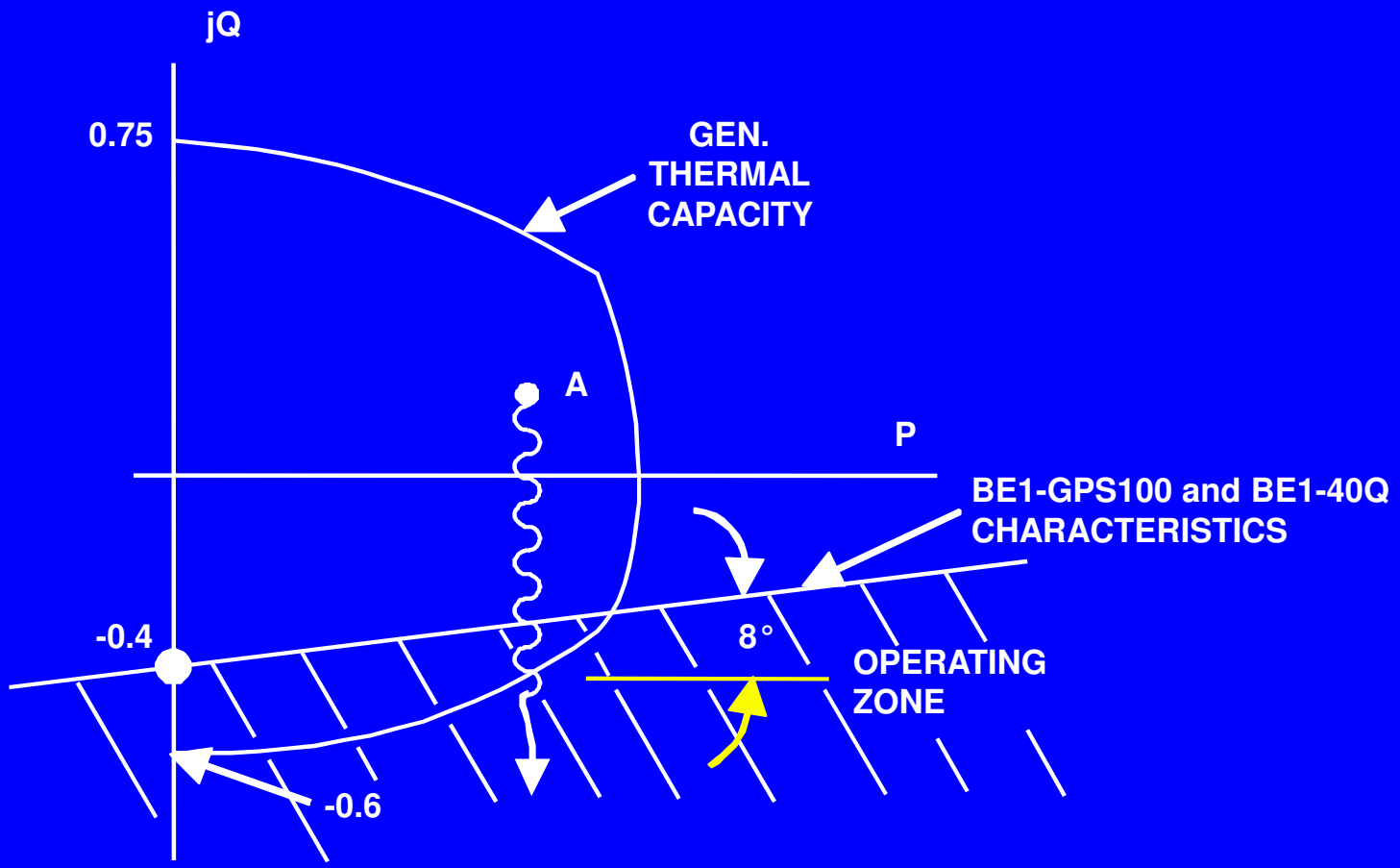
- Loss of field can cause voltage reduction and oscillation - adverse effect on sensitive load.
- If unit is large compared to external source system, system instability can result.
- 40 provides loss-of-field protection
  - time delay of 0.1 sec. is recommended to override transient load swings
  - timer is included in the relay

Basler

Loss-of-Field Protection



Loss-of-field protection: Power trajectory



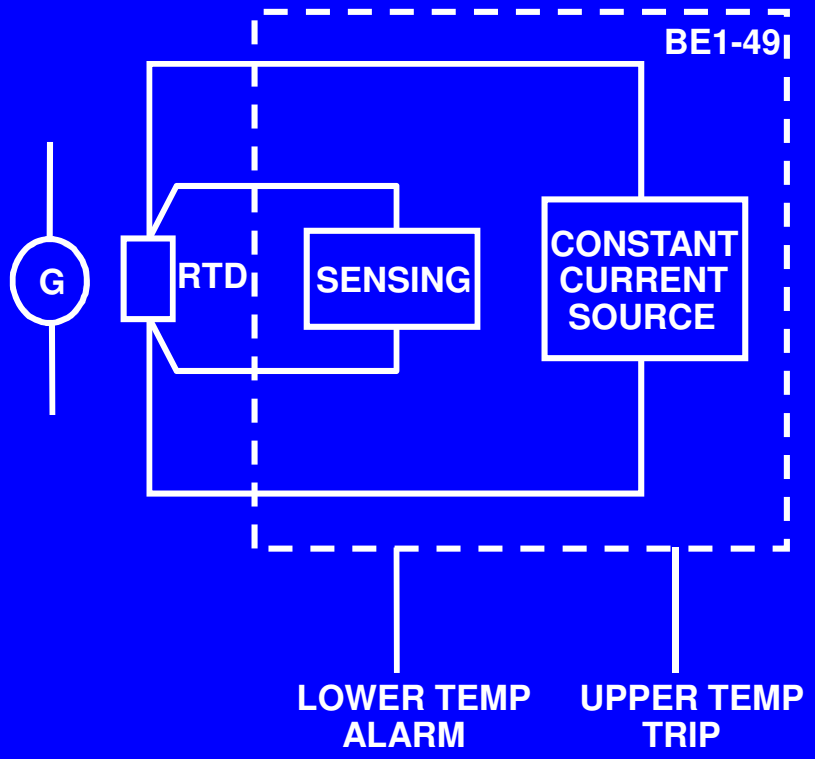
- First quadrant of diagram applies to lagging PF; fourth quadrant applies to leading PF
- Trajectory starts at point A, moves to a point in 4th quadrant
  - can exceed thermal capability of machine

Thermal Protection

Stator thermal protection relay (49) connected to resistor temperature detector embedded in stator slot

Typical settings:

- Alarm 120 ℃
- Trip 130 ℃



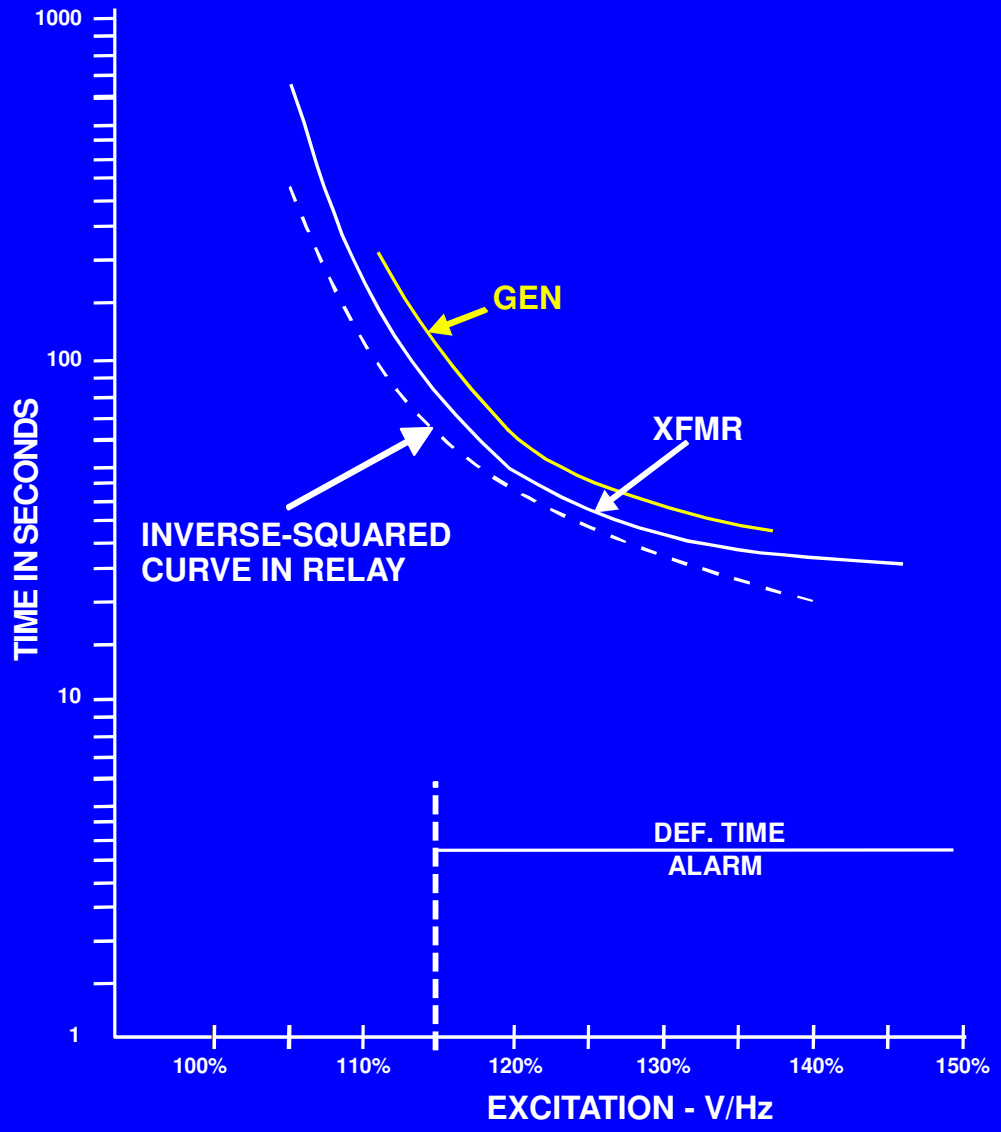
Basler

Overexcitation protection

- Overexcitation can occur due to:
  - higher than rated voltage
  - lower than rated frequency at rated or less than rated voltage
  - unit off line and voltage regulator out of service or defective
- Overexcitation condition produces thermal stress to the generator.
- IEEE C50.13 specifies that generator should withstand 105% of rated voltage at full load.
- With unit off line and voltage control regulator at reduced frequency (without overexcitation limiter), overexcitation can occur.

Basler

Overexcitation protection



- 24 provides V/Hz protection.
- 24 and voltage regulators should be provided with separate ac potential sources.
- Curve indicates 24 characteristic and generator withstand capability.

Negative Sequence Overcurrent Protection

CAUSE:

Negative sequence currents could result from:

- Unbalanced loads
- Asymmetrical faults
- Open phase conditions

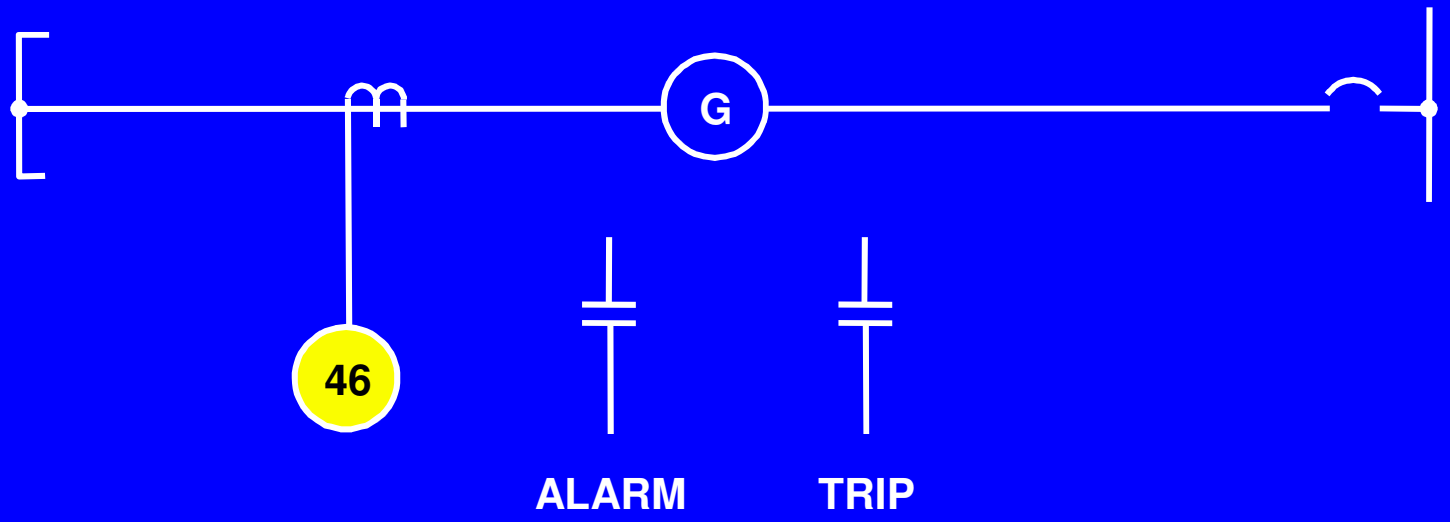
DAMAGES:

Negative sequence current induces double frequency current in rotor winding.

-> overheats the iron surface, retaining rings, slot wedges

Basler

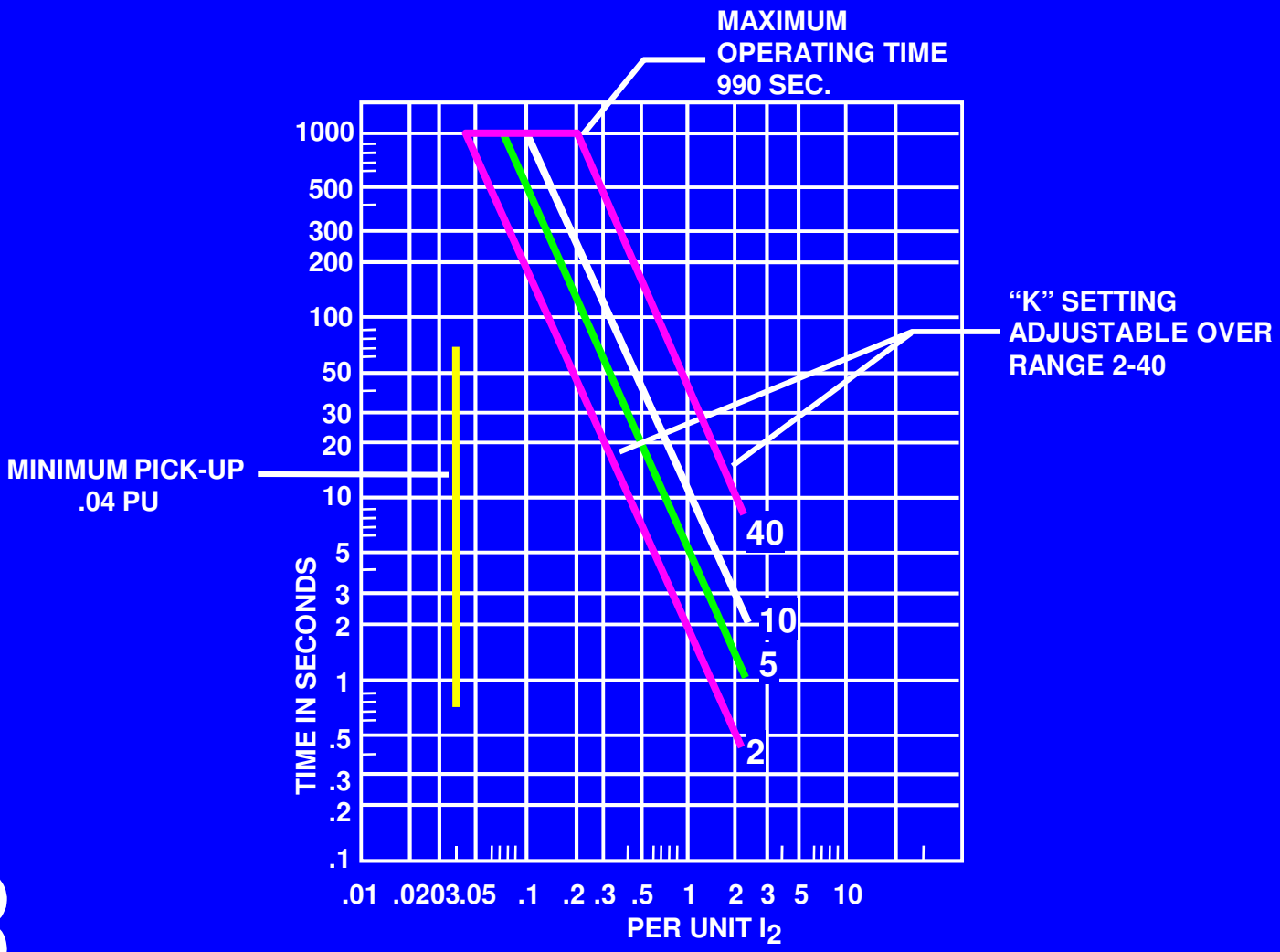
Negative Sequence Overcurrent Protection



- Generator should be able to withstand 5-10% of continuous I_2 current
- Short term capability is specified by I_2^2t limit ("K= I_2^2t" with k : Generator thermal capacity constant)

Basler

Characteristics of a Static Negative-Sequence Time-Overcurrent Relay



Basler

Student exercice

Generator K factor = 10

Generator nominal current In

Negative sequence current I2 = 30% of In

What is the maximum time generator will withstand I2?

t = K / I2^2; t = 10/0.3^2 = 111 s

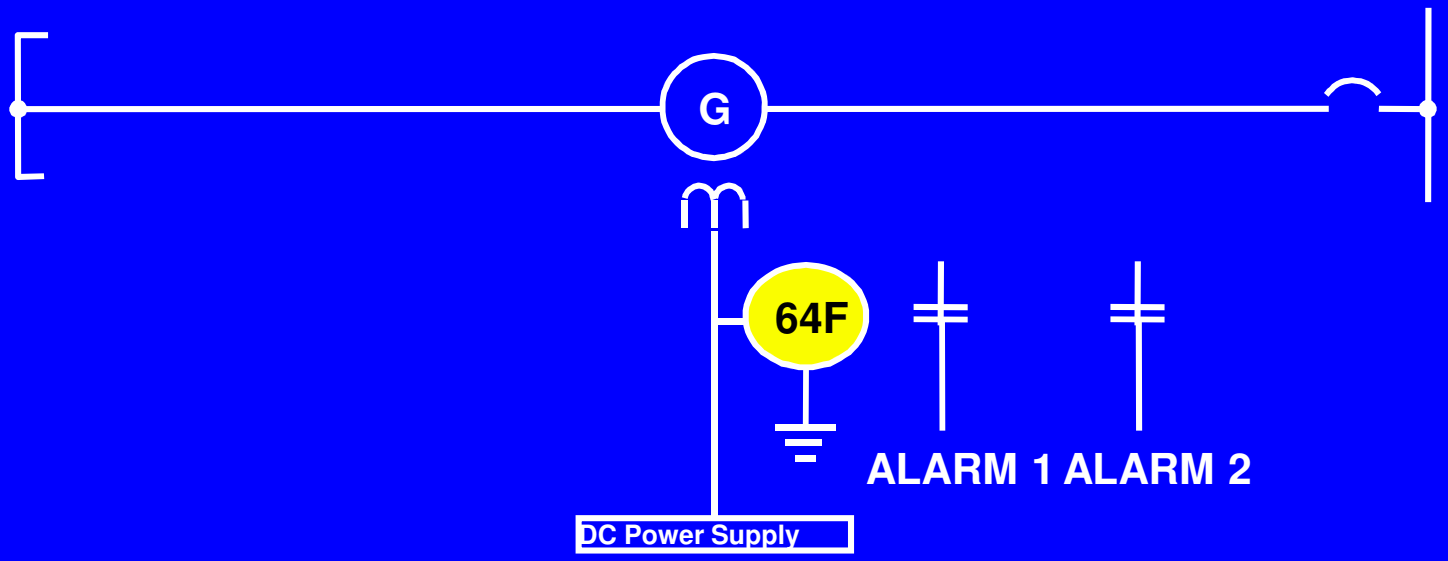
Basler

Off-frequency operation

- Diesel engines safely operated at off-frequency
- Gas turbine controls provide protection for
  off-frequency operation.
- Frequency relays applied to steam turbine units to minimize turbine blade fatiguing

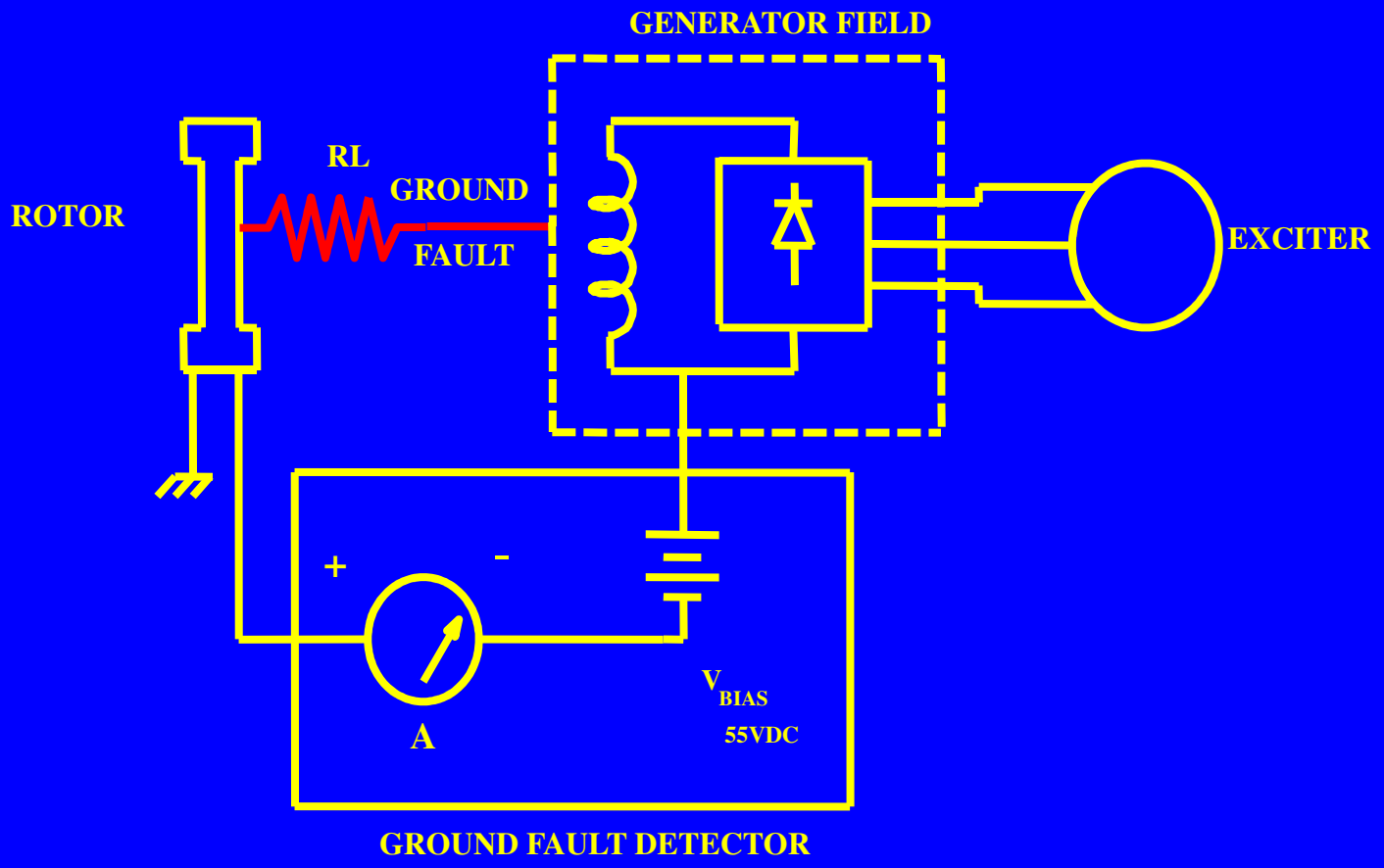
Basler

Field Ground detection 64F



Check insulation level of the exciter field

Field Ground detection 64F



Basler

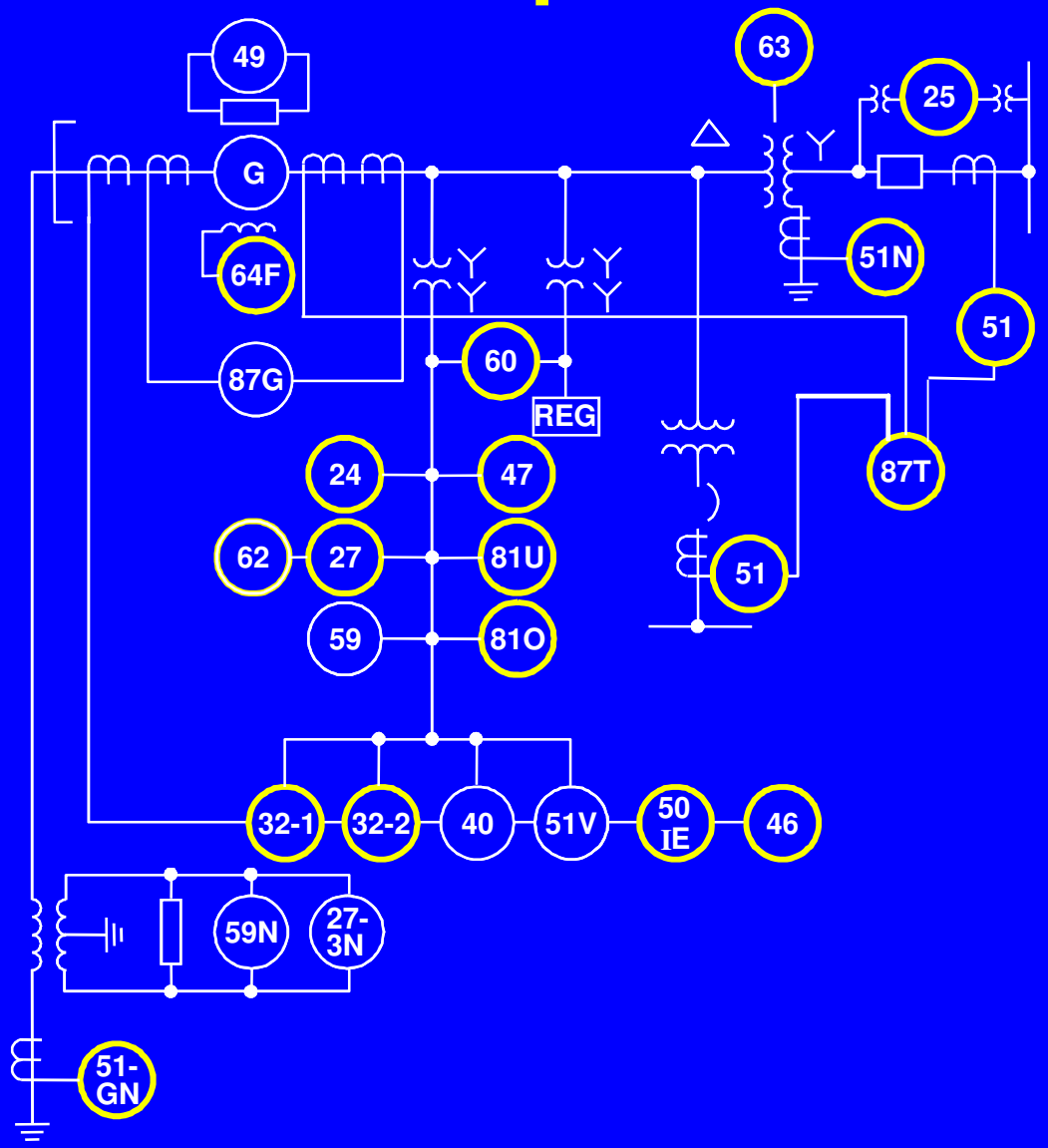
Field Ground detection 64F

- In normal operation, rotating circuit-generator rotor, exciter an diodes is completely insulated from the shaft.
- Accidental ground doesn’t affect operation.
- Problem arise in case of 2nd ground fault :
  - magnetic unbalanced
  - Vibration appear increasing with the excitation current
  - Shaft deformation: rotor will touch the stator

Basler

INTEGRATED APPLICATION EXAMPLE

Integrated application examples: Extended protection



Questions?